Studies of Mine Burial in Coastal Environments

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LONG-TERM GOALS

The long-term goal of our research program is to improve scientific knowledge relevant to the understanding and modeling of fluid dynamic and sedimentary processes related to the burial of mines in coastal oceans, with the hope of greatly improving the predictive capabilities of MCM operations of the U.S. Navy. The main focus is non-walking ship mines of cylindrical shape placed in the shoaling zone.

OBJECTIVES

A review of literature reveals the need for integration of several technical areas of expertise to advance the development of physics-based models for mine burial predictions, which include near and far field mechanics of environmental factors and coupled sediment (soil)-structure-fluid interaction processes. The scientific objectives of our current research are to: (i) study the evolution of an initially smooth sandy beach under nonlinear progressive waves; (ii) investigate the long-term evolution of bottom topography in relation to various mine burial scenario, and (iii) analyze the behavior of mines in the shoaling zone. Particular attention is given to: (i) the water motion and ensuing scour around cylindrical mines placed on a sandy slope under progressive nonlinear waves; (ii) morphodynamics of sand beds under water waves; and (iii) periodic or lasting burial of model mines.

APPROACH

In this research, the Arizona State University (ASU) investigators combine their expertise in laboratory and theoretical fluid dynamics with the complementary wave modeling expertise of Stephan Grilli of the University of Rhode Island (URI) to better understand and model processes related to mine burial in shoaling waters. The research is directed at developing science-based parameterizations of

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14. ABSTRACT
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15. SUBJECT TERMS

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scour/burial processes, with the goal of incorporating them into probabilistic models under development. Detailed laboratory observations are made in all phases of wave evolution, wave-mine interaction and bedforms evolution, with the hope of developing physical insights and new parameterizations to improve existing models and develop new ones.

WORK COMPLETED

Our previous studies were concentrated mostly on the numerical simulations of progressive waves on a slope (Grilli & Horrillo, 1999; Grilli et al., 2001) and behavior of disk-shaped model mines on horizontal and sloping beaches under oscillatory flows (Lucccio et al., 1998: Voropayev et al., 1998, 1999, 2001a-c). In the present work, the above research is extended to include relatively large cylindrical mines placed on a sandy slope under progressive shoaling waves generated in a large wave tank located at ASU (Fig. 1). In parallel, numerical simulations are conducted using a similar (in size) numerical wave tank (NWT).

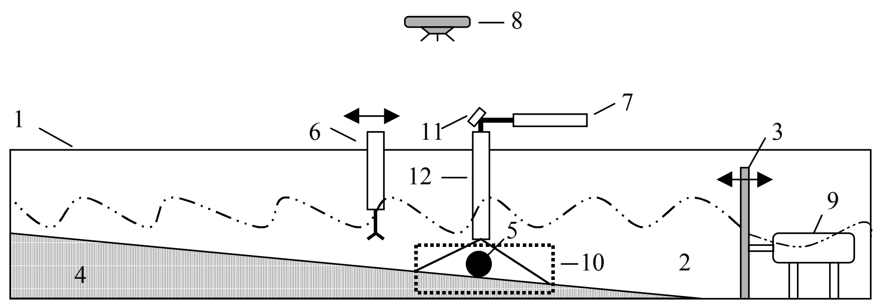

Figure 1. Schematic of the experimental system: 1 – tank, 2 – water, 3 – vertical wave-maker (frequency - ω, amplitude of horizontal displacement - ε_0), 4 – sloping bottom (slope = 1/24), 5 – mine, 6 – acoustic Doppler velocimeter attached to carriage, 7 – laser, 8 – photo/video camera, 9 – hydraulic system to move wave maker, 10 – view frame of a digital camera which is connected to a computer, 11 – mirror, 12 – light guide with splitting optics under the water level.

In the laboratory experiments, quantitative data on the background flow characteristics, scour/burial of mines and the changes of bottom topography are obtained using a suite of instruments. These include high-resolution video cameras, three-component acoustic Doppler velocimety (ADV), "structural" light technique, wave gauges and other state of the art flow diagnostic techniques such as particle image velocimetry (PIV). The temporal evolution of the bed profile and velocity field in the far and near fields of the model mines (short cylinders) placed on the sandy bottom of the wave tank are also studied. Experiments are conducted at relatively high Reynolds numbers and for a range of flow conditions that can be specified by the Keulegan-Carpenter number KC and the Shields Sh parameter.

RESULTS

Our research during FY 02 was mainly focussed on the (i) far field flow under nonlinear waves propagating along a sandy slope, (ii) near field water motion around mines, (iii) burial/scour around cylindrical mines placed on the slope and (iv) bed morphodynamics. Experimental data on far field flow in the shoaling zone were collected and used for the calibration and validation of numerical

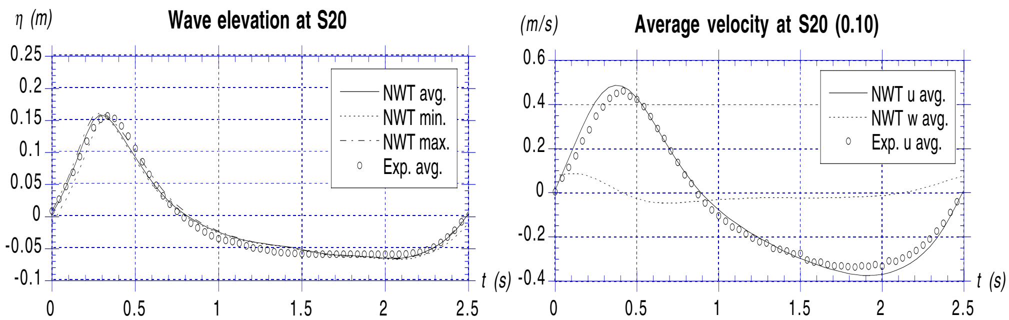

Figure 2. Comparison of measured and computed wave elevation, η, and horizontal velocity, u, in section #20 of laboratory and numerical tanks. Note the asymmetry and skewness resulting from the nonlinearity of shoaling waves. Results were averaged over 40 wave periods.

models (Fig. 2). Using these data as boundary conditions, simulations on the near field mine/flow interactions have been conducted (using the commercial software package FLUENT).

Depending on the values of KC and Sh parameters, four different scour regimes around the cylinder as well as periodic burial of cylinder under migrating sand ripples were observed. These regimes were classified as: (I) no scour/burial, (II) initial scour (Fig. 3), (III) expanded scour (see Fig. 4) and (IV) periodic burial cases.

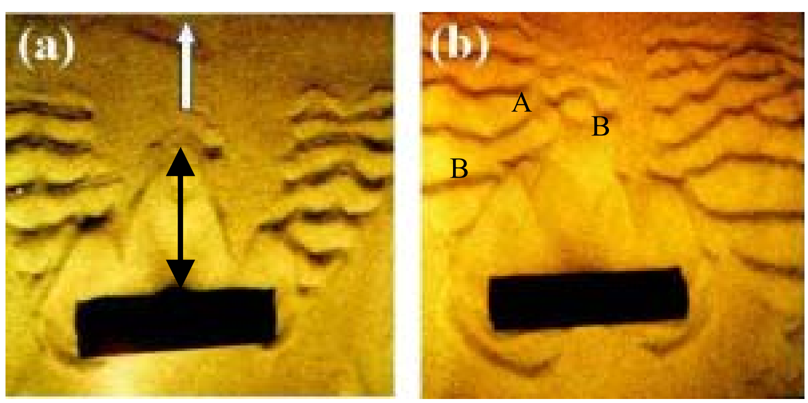

Figure 3. Initial scour patterns (Regime II) around a cylinder. White arrow shows the onshore direction, black arrow shows the maximum equilibrium scour length, L*. Time t = 120 (a), 220 (b) min after the initiation of wave forcing, A - central scour gap, B - tip scour gap. Re = 20000, KC = 10, Sh = 0.082.

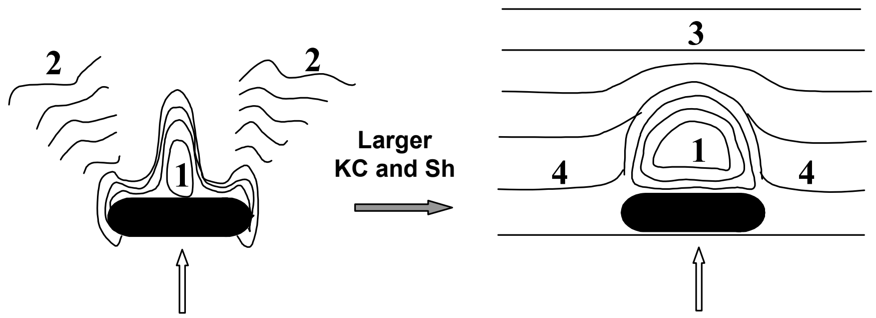

Figure 4. A schematic of the transformation of initial scour pattern (regime II) to the expanded scour (regime III) for larger values of KC and Sh parameters when the diameter of the cylinder D is larger than the ripple height h (i.e. D/h>1). Vertical arrows show the onshore direction. (1) - central gap, (2) - sand waves generated near cylinder tips and propagating under approximately 40 degrees from the cylinder, (3) - undisturbed incoming ripples, (4) ripples around the scour gap.

A scour/burial regime diagram (Fig. 5) was developed and demarcation criteria between different regimes were identified.

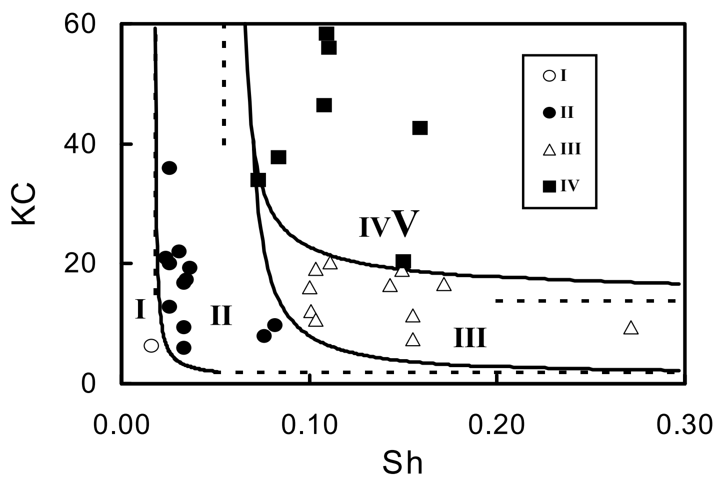

Figure 4. The KC-Sh regime diagram that shows the four different scour/burial regimes (I-IV) identified above. Three solid lines show transition curves between the four basic regimes The dashed lines show analytically derived limiting asymptotes for different regimes.

Data on the score depth, S, and length, L, as functions of time, KC and Sh were collected using the “structural” light technique (Fig 5). Semi-empirical formulae that permit estimation of the scour depth with time, the equilibrium maximum scour depth and length, and conditions necessary for the burial of the cylinder as a function of main external parameters were proposed.

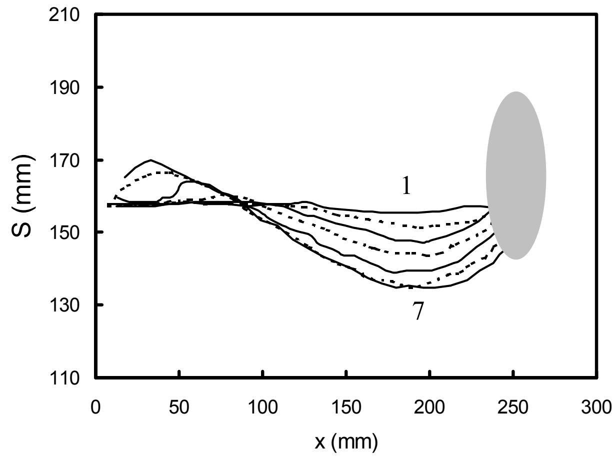

Figure 5. Scour evolution profiles at the center of the scour gap for initial scour (regime II). Different scaling are used for the horizontal, X, and vertical, S, directions, as a result of which the circular cylinder is seen as an ellipse (gray color). Times for the profiles 1 to 7 from the beginning of the experiment are t= 0, 1.5, 5, 15, 40, 100, 140 min. Onshore direction is to the left.

For example, the dependence of the non-dimensional scour depth S/D (D - cylinder diameter) on KC, Sh and non-dimensional time, t/t^* ($t^* = c/\omega$, ω - wave frequency) is given as

$$S/D = C[1 - \exp(-t/t^*)]\,[1 - \exp(-m(KC - KC^*))]\,[1 - \exp(-n(Sh - Sh^*))], \qquad (1)$$

wherein the theoretically estimated critical values are $KC^* \approx 2$, $Sh^* \approx 0.018$ and the empirically determined constants are $C \approx 1.3$, $c \approx 3300$, $m \approx 0.06$, $n \approx 40$ (for example, see Fig. 6). The results are described in detail in Grilli et al. (2002) and Voropayev et al. (2002a,b).

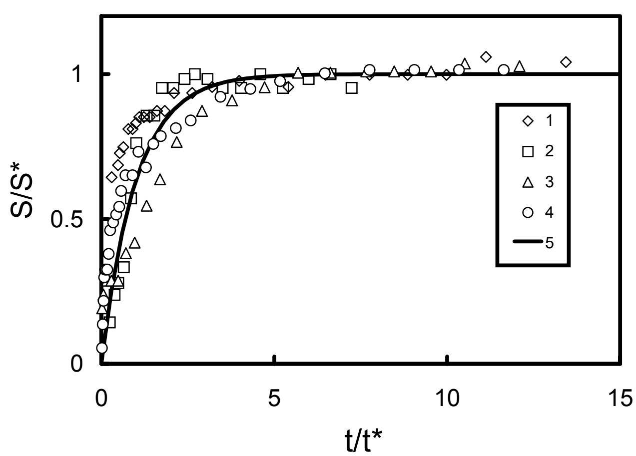

Figure 6. A plot illustrating the growth of non-dimensional scour depth S/S* at the center of the cylinder with non-dimensional time, t/t* for four different experiments. Symbols (1-4) are the results of the measurements, solid line (5) shows the function (1) for constant (for each experiment) values of KC and Sh. Experimental parameters: D = 5 cm, ω = 0.4 Hz, KC = 10, Sh = 0.076 (1), 5, 0.2, 14, 0.035 (2), 5, 0.3, 9.4, 0.033 (3), 5, 0.4, 10.5, 0.076 (4).

IMPACT/APPLICATIONS

The scour and burial around large dense cylindrical objects, such as ship mines, located on a sandy sloping bottom and submerged in the wave boundary layer of coastal zone has not been well understood from a fundamental point of view. This project has made fundamental advances in this regard by utilizing integrated laboratory and theoretical/numerical approaches. The laboratory results will be scaled to the ocean conditions of the mine burial field experiment, based on which predictions will be made for mine burial scenario expected during the field campaign. Comparisons between laboratory and field observations will help evaluate the efficacy of laboratory experiments in developing operational models as well as determine which critical dimensionless variables need to be emphasized in future laboratory modeling. The evaluation of the URI wave model using the data will establish the versatility of the model as a future research tool.

TRANSITIONS

Our data are being extensively used by the Mine Burial Expert System (ES) Development Group (Alan Brandt and Sarah Renee) at the Johns Hopkins University Applied Physics Laboratory for system training. JHU ES system is expected to become an operational tool for the Navy.

RELATED PROJECTS

This project is linked to another laboratory modeling program funded by the ONR Coastal Sciences Program on mine walking in swash zone. This projects ends in October 2002.

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